# DEALING WITH GEOLOGICAL DISCONTINUITIES IN SAFETY ASSESSMENT: THE APPROACH OF THE FRENCH TECHNICAL SAFETY ORGANISATION

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## Abstract

The present paper focuses on IRSN structural studies aiming at assessing the existence of tectonic structures in the Callovo-Oxfordian clay formation and their potential role on radionuclide transport. IRSN has first determined the type of fracturing that could be present in the Callovo-Oxfordian, by carrying out surface fieldwork in Meuse/Haute-Marne and investigations in clay and limestone layers in the Tournemire experimental station. IRSN has also examined the results of the Andra 3-D seismic survey associated with inclined boreholes around the Bure URL, as well as the limits of these survey methods, based on its own 3-D High-Resolution seismic survey campaign carried out in Tournemire on fault zones already recognised by drifts and boreholes. At the scale of the Paris sedimentary basin, on the basis of a geological model and of measured hydrodynamic parameters, IRSN has developed underground water flow schemes, which allow the determination of possible water pathways, outlets and associated transfer times. This modelling shows that several combinations in the representation of tectonic structures are possible to fit measured data, and that the remaining uncertainties regarding their hydrogeological role should be reduced. In addition, the influence of a hypothetic fault in the Callovo-Oxfordian clay close to disposal cells on radionuclide molar flows is tested at the repository scale. At last, perspectives are given regarding in particular methods to detect hydrogeologically active faults, differential fracturing patterns in clays and limestones as well as improvement of IRSN hydrogeological model.

## Introduction

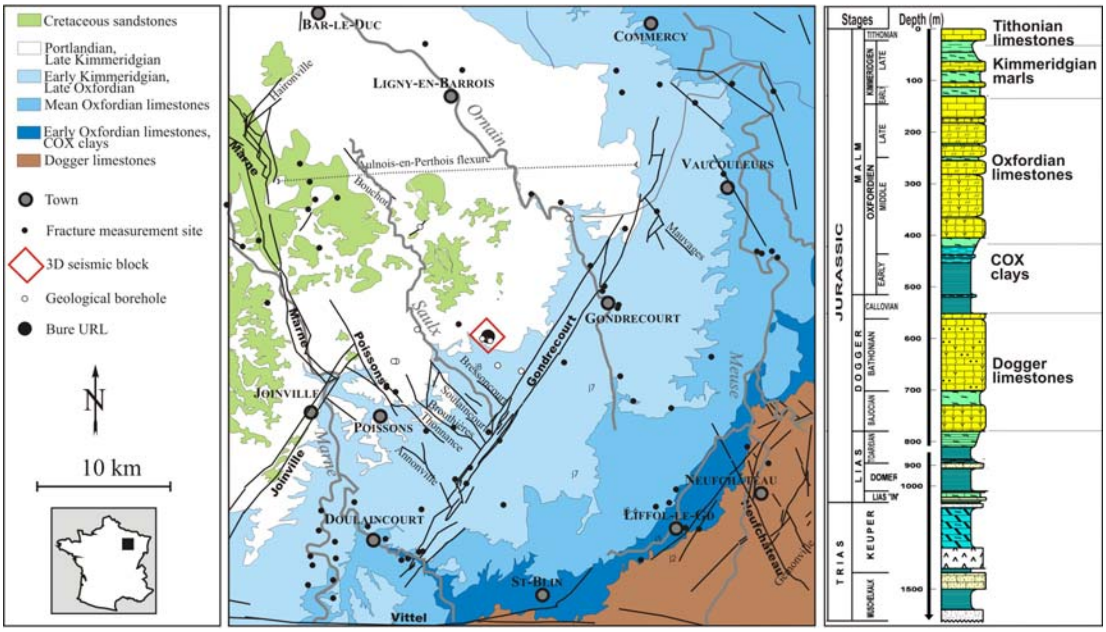
IRSN has reviewed Andra 2005 clay dossier on the feasibility of deep geological disposal of high level, long-lived radioactive waste in the Callovo-Oxfordian clay formation (COX) located in the Meuse/Haute-Marne (MHM) area, eastern Paris Basin, and investigated by Andra using the Bure URL. In order to prepare this review, IRSN performed specific studies to address safety questions, among which issues related to possible preferential flow transfer throughout geological structures. In this context, the present paper focuses in a first section on IRSN work devoted to assess the possible existence and nature of tectonic structures in the COX, as well as the survey methods to identify such structures. The second section of this paper deals with their role on underground water flows and radionuclide transport.

It is worth noting that in this paper, a fault designates a fracture formed by shearing (relative motion between its edges), regardless its size. It is called “regional” when its vertical offset is greater than 10 m and/or its horizontal extend is over 10 km, “secondary” if its vertical offset is between 5 and 10 m and/or its extend from 1 to 10 km, and “minor” if its vertical offset is less than 5 m and/or extend less than 1 km long.

## Characterisation of structural discontinuities in the COX

The geological setting of the MHM area is a platform with Mesozoic outcropping units gently tilted to the WNW (Figure 1). It is surrounded by several regional faults, to the North by the N060° Metz Fault, to the South by the N090° Vittel Fault, and is limited by N040° faults (Joinville and Gondrecourt Faults) and N160° faults (Marne and Neufchâteau Faults) (Stchépinsky, 1960; Andra, 2005).

Figure 1. **Structural setting of the MHM area (Stchépinsky, 1960; Andra, 2005) and stratigraphic log according to Andra (2005) at Bure**




### *Existence and nature of structures in the COX*

In the numerous seismic reflection profiles and boreholes drilled until 2 000 (recently by Andra or earlier for petroleum investigations), no structure in the COX was reported, except when intersecting regional faults (Figure 1). However, IRSN considered that this local data did not allow to conclude whether the COX could be affected by secondary faulting in MHM between these regional faults.

As usually for clay formations, the outcropping COX in the MHM area is not suitable for structural analyses due to the breaking away of clayey rocks laying at surface and the associated development of vegetation. On the opposite, outcropping limestones are better preserved and observable. In 2000-2002, in order to determine the type of fracturing that may exist in the COX, IRSN thus carried out a statistical analysis (see Rocher *et al.*, 2004) on about 2 000 fracture measurements, from 63 sites in the MHM outcropping Jurassic limestones, i.e. Dogger, Oxfordian and Tithonian rocks (Figure 1). Half of the data corresponds to faults with strike-slip or normal sense, half to orientation of joints, veins and stylolitic peaks. The veins correspond to tension gashes or to former joints filled with calcite. Figure 2 gives an illustration of the results. This kind of fracturing, i.e. several times reactivated structures, mainly represented by subvertical joints and minor to secondary faults with normal or strike-slip sense, is classical of intraplate tectonic platforms.

The second step of IRSN structural study was to determine if these fracturing characteristics determined in the MHM limestones could be inferred to COX clays. In this objective, IRSN has examined discontinuities both in limestones and clays in a single site located at Tournemire (Aveyron, France; Figure 3). Fracturing in clays was observed in an ancient railway tunnel and in drifts crossing a 150 m thick Toarcian clay formation, at a depth of 250 m in IRSN Tournemire experimental station; fracturing in limestones was observed in the outcropping Aalenian-Bajocian formations located above the station.

Figure 2. **Azimuths (a) and slopes (b) of 1- all faults and joints, 2- normal, strike-slip, and reverse faults measured in MHM** (Rocher et al., 2004)

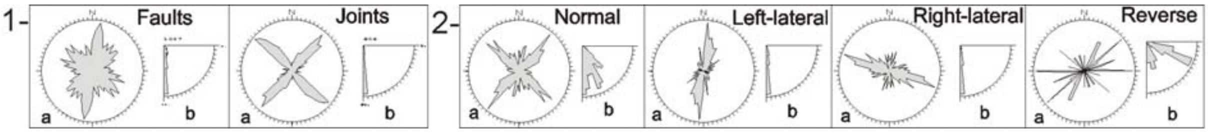
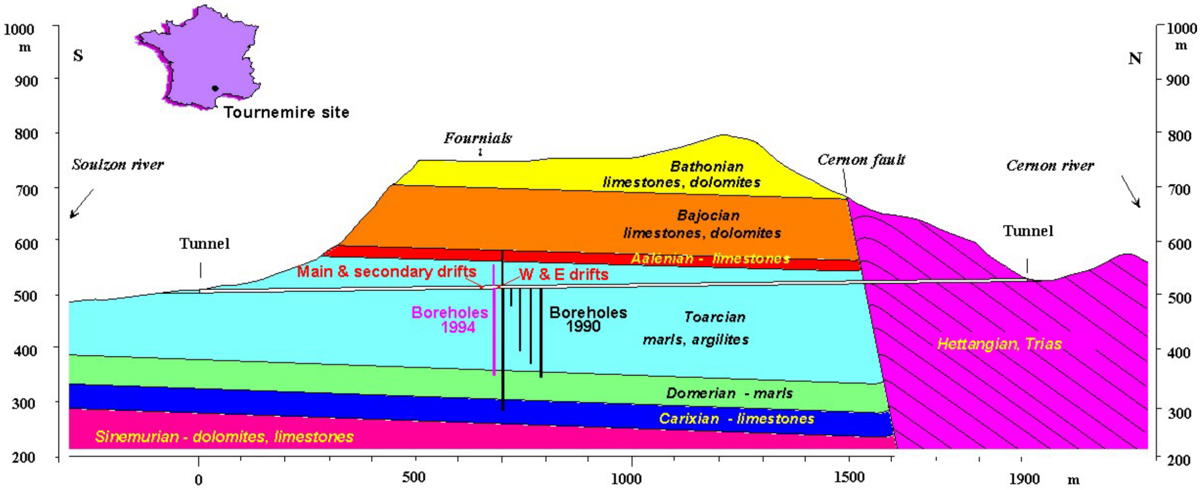



Figure 3. **N-S geological cross-section of IRSN Tournemire experimental station** (Cabrera, 2002)




It is worth noting that the geological context for the Toarcian clays is quite similar to that of the COX, i.e. composed of a tabular superposition of limestone and clay layers of hundreds of metres thick (Figure 3). The Tournemire site could be in that sense considered as geologically analogous to the MHM area. Nevertheless, differences exist among which:

- The distance from the Tournemire drifts to a regional fault (Cernon fault, see Figure 3) is smaller than the distance from the Bure URL to regional surrounding faults (Figure 1). As a consequence, one can expect an increased tectonic fracturing at the Tournemire site.
- The depth of the tunnel and drifts in the Toarcian clays is half the depth of the COX URL. As a result, surface effects such as stress release are expected to have greater impact in Tournemire.
- The Toarcian clays were suspected to have been buried at greater depth (Barbarand *et al.*, 2001) during their geological history than did the COX (Andra, 2005). This could explain why both clays do not have exactly the same mechanical properties. In particular, the Toarcian clays are mechanically slightly stiffer than the COX. Therefore, intraplate tectonics could have induced more fractures in the Tournemire case.

The structures measured in the Tournemire Toarcian clay formation have a typical signature of intraplate tectonics (Constantin, 2002): fractures were reactivated several times, minor to secondary faulting occurred with normal or strike-slip sense, as do tension gashes filled with calcite (Figure 4).

Furthermore, IRSN has observed that fracturing is similar in Tournemire clays at depth and in outcropping limestones, except in terms of fracturing density, which IRSN attributed to the clays' less brittle mechanical behaviour.

Figure 4. **Tectonic structures observed on Tournemire drift walls: 1- calcite vein, 2- normal fault striae**


IRSN concluded, at this stage, that the COX in MHM might also be locally impacted by tectonics as in the surrounding limestones in MHM, even though differences can be expected between clays and limestones, in particular concerning the fracture density.

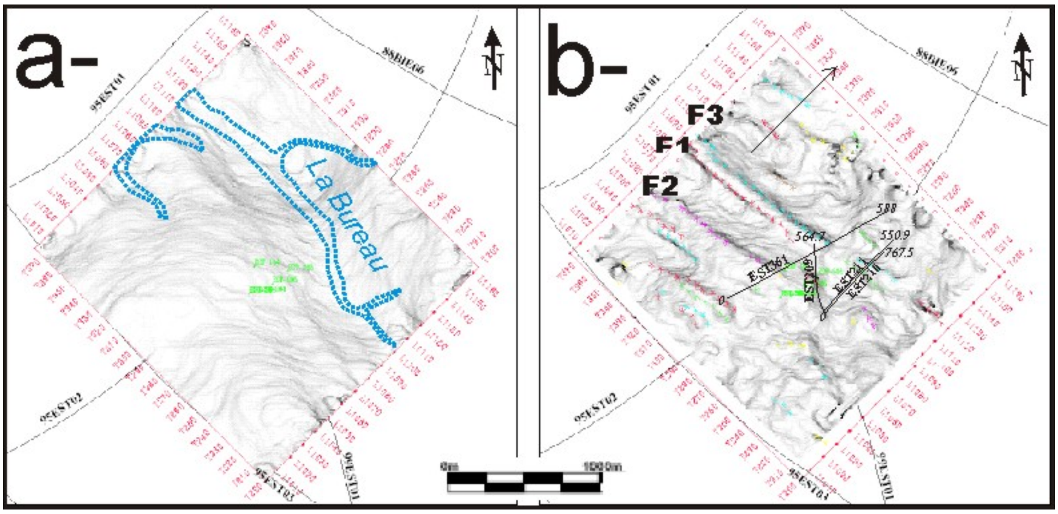
***Survey methods aiming at detecting a secondary structure in clay formations***

*3-D seismic reflection survey in MHM*

In 1999, Andra carried out a 3-D geophysical seismic campaign over a 4.35 km² surface area around the Bure URL. After a first processing in 2002, Andra reprocessed the 3-D seismic block in 2003, using static corrections, raising its frequency from 100 to 140Hz and increasing its signal/noise ratio. The results indicate that the lowest detectable fault slip is between 2.5 and 4 m, depending on the geological formation. This campaign notably showed subvertical seismic anomalies (Figure 5b) oriented N130° and spaced 200-300 m, affecting the Mesozoic formations to the Middle Dogger (Lower Bathonian; Andra, 2005). The two most pronounced N130° anomalies are located in the north-western half of the seismic block. In the Lower Bajocian, they show an at least 1-km extension (given their possible extension beyond the 3-D seismic block) and a vertical slip over 5 m at their northern end (Figure 5b, F1 and F3). Furthermore, at this stage of knowledge, IRSN concluded that two anomalies are rooted in the basement (Paleozoic) in the northern part of the seismic block (Figure 5b, F2 and F3).

However, no seismic signal indicating the presence of tectonic structures was visible in the layer located at the top of the Dogger ("Dalle Nacrée", Figure 5a). The same way, no structure was detected in the 3-D seismic block in the COX and Oxfordian layers (Andra, 2005). The observed 3-D seismic anomalies let IRSN to consider, based on the available information, that these anomalies have a tectonic origin. Actually, the hypothesis of a synsedimentary faulting origin (sealed in the Late Dogger) should not be ruled out, but these faults with a subvertical slope could also relate to strike-slip faults, e.g. belonging to the Marne-Poissons faults family. For IRSN, the absence of seismic anomaly from the top of the Dogger to the surface could indicate that the vertical offset, if still present from the top of the Dogger to the surface, is beyond the detection limit for the 3-D seismic survey method.

Figure 5. **Dips at the surface of the Dogger top (a) and of the Longwy marls bottom (b), from the 3-D seismic reflection campaign around the Bure URL (according to Andra, 2005). Curved lines outside seismic 3-D block indicate 2-D seismic profiles. a- Blue dots indicate surface water courses. b- Location of the oblique boreholes drilled by Andra in 2003-2004 with reached depths in metre**




Regarding the survey methods, IRSN noted that these anomalies were not detected on the 2-D seismic profile (95EST02, see Figure 5) that cross-cuts the 3-D seismic block and thus confirmed that the 3-D seismic reflection survey method had a better resolution than the 2-D survey method.

*3-D seismic reflection survey at the Tournemire site*

In order to test its ability to detect fractures with minor vertical offset in clay formations, IRSN has tested in 2001 a High-Resolution (HR) 3-D seismic survey method on minor and secondary strike-slip faults (Figure 6) in Tournemire (see Rocher *et al.*, 2008). The "Tournemire" fault was first recognised in clays during the drifts' excavation and in boreholes; this hectometre-sized subvertical fault set, displaying a 2 m vertical offset and larger horizontal offset, varies in space, from a dry metre-sized fault gouge showing the same aspect as the intact rock (see Figure 6) on some of the drift walls, to a wide and hydraulically active breccia associated with a fractured zone tens of metres wide elsewhere.

The experimental device, developed on a 0.5 km$^2$ surface area, contained thirteen E-W receiver lines of 10-m spaced "traces" (95 traces; 6 geophones by trace) and twenty N-S source lines 50 m spaced. An additional line of six geophones placed in the Western and Eastern drifts (at -250 m) measured the direct paths. The source (vibrator trucks) had a frequency range of 14 to 140 Hz (calibrated using reference tests on the geologic media's response).

A first processing phase involved linear noise filtering, signal amplitude processing, primary static corrections, dynamic corrections, "Mute" adjustment, residual static corrections and migrations (dip moveout and time) as well as additional processing by 3-D filter "FK". The seismic maps and profiles allowed to detect the main N-S fault in the underlying limestone layer (Figure 7), but not in the clay layer itself. The west drift's secondary fault was not detected and for the overlying limestone, the data was altered by seismic surface noise.

In a second processing phase, a "coherence cube" method and a seismic facies analysis were carried out, as well as an azimuth anisotropy study around the fractures. The seismic interpretation (Figure 8a) showed an improved detection of structures in the underlying limestone layer (better resolution): the main N-S fault and other NW faults such as “Tournemire” fault were detected. Though these faults were still not identified within the clay layer (Figure 8b), they were partially detected at the interface between the underlying limestones and the clay layer.

Figure 6. **Structural scheme at -250 m of the faults in the central part of the Tournemire experimental station, and photograph of the “Tournemire” fault** (Cabrera, 2002)

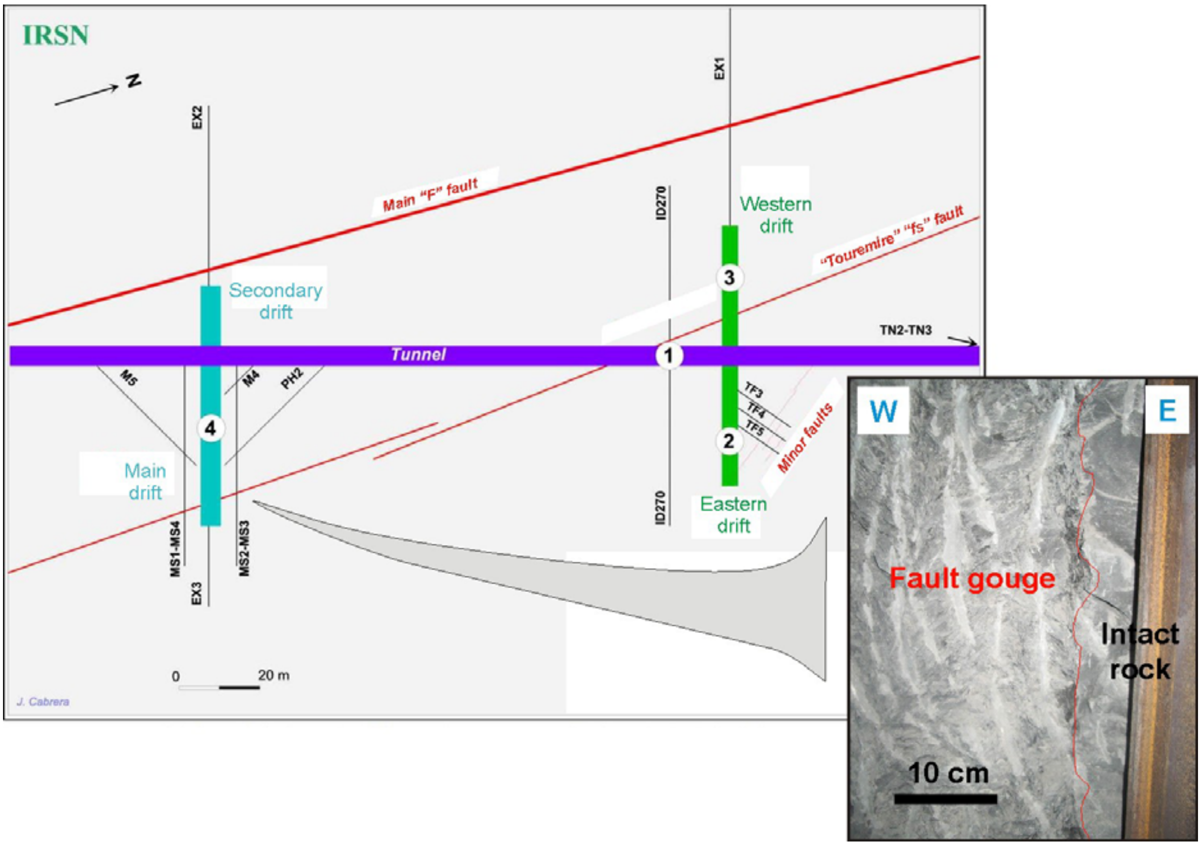



Figure 7. **Migrated 563 cross-line (Figure 8), cross-cutting the Tournemire tunnel, showing the main fault “F” in the clay’s underlying limestone layer UL (Aalenian-Bajocian-Bathonian) OL: overlying (Carixian) limestone layer, Cl: Toarcian clay layer** (Cabrera, 2002)

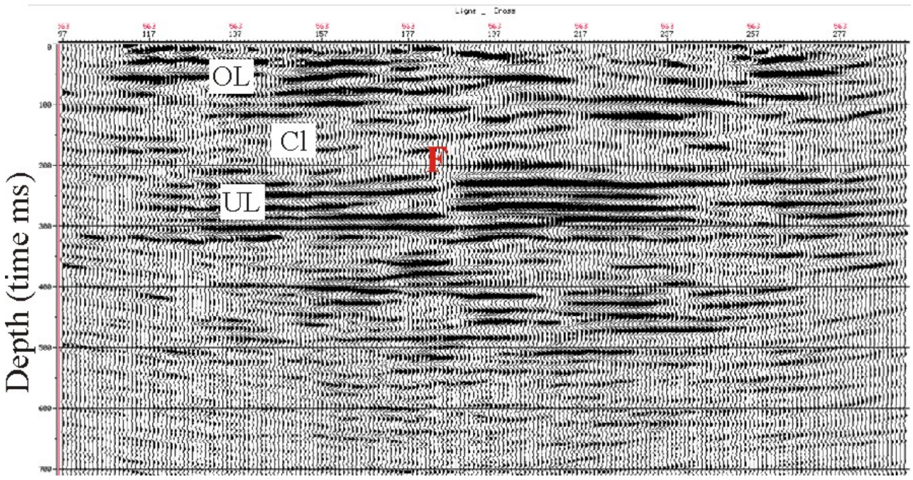
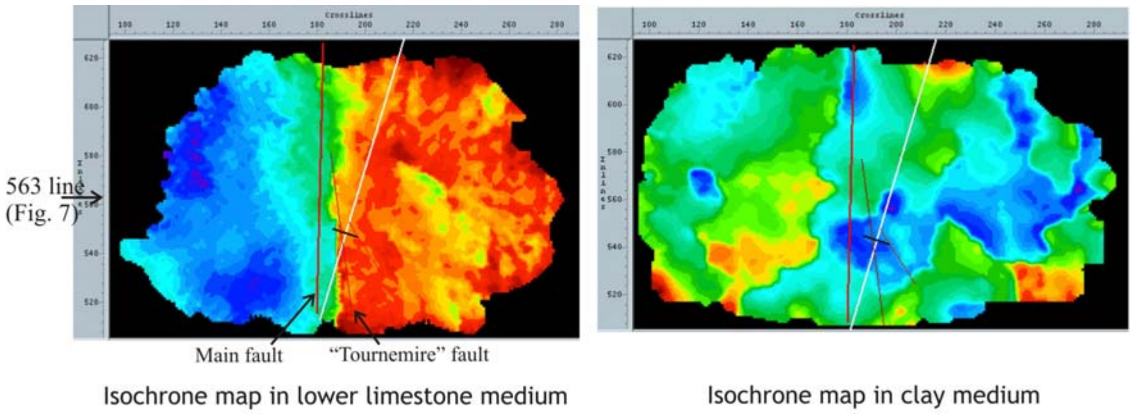


Figure 8. **Isochrone maps, at 470 m depth in the lower limestones (a) and at 250 m depth in the Toarcian clays (b). Tunnel in white, western and eastern drifts in black, faults in red** (Cabrera, 2002)




The 3-D HR seismic tests applied from the surface in Tournemire let IRSN to conclude that locally transmissive faults may not be identified by seismic reflection survey methods at the scale of a potential repository due to a minor vertical offset. As a consequence, IRSN recommended in its review in 2002 that the 3-D seismic reflection survey carried out in the MHM area should be combined with additional methods so as to reduce the uncertainty related to the presence of structures.

*Oblique boreholes drilled by Andra in MHM*

In 2003-2004, Andra drilled four oblique boreholes that went upward from the 3-D seismic anomalies, in the COX (EST 209, 211, 361) and in the Late Dogger (EST 210; Figure 5b). However, tectonic faulting was neither revealed in the core samples of these boreholes nor from the FMI (Fullbore Formation MicroImager) performed in the EST210 borehole. Based on the elements presented above, IRSN concluded that there was no hydraulically transmissive structure in the COX in the zone surveyed using the boreholes located within the 3-D seismic block.

Besides the anomalies previously assessed, IRSN noted that the secondary faults belonging to the Marne-Poissons faults family possibly detected using two Andra boreholes located a few kilometres north of Poisson town (Figure 1a) may have a hydraulic role. Indeed, the fluids sampled in the Dogger seemed to correspond to a mix with fluids from the Oxfordian aquifer. IRSN postulated that in the vicinity of these boreholes, faults may hydraulically impact the entire sedimentary pile, including the COX.

Thus, given the difference in fault propagation between both cases (seismic anomalies and Marne-Poisson family), it cannot be concluded whether structures with similar origin can have propagated across the COX. The propagation of fractures from limestones to clays is related to the so-called "differential fracturing phenomenon", which means that the ductile layers (clays) show a less intense and localised fracturing than the breaking layers (such as limestones). This phenomenon is commonly observed (see observations in Bure URL from André *et al.*, 2006) and has already been studied for joints at the metre scale, but IRSN considers that it is still insufficiently understood for faulting at the scale of 100 metres thick formations.

As a consequence of the above considerations (i.e. no transmissive fault observed using the oblique boreholes'survey but transfers through fracturing in the COX suspected elsewhere; poorly understood fracturing phenomenon), IRSN considered that the COX may have an important potential to dampen fracturing, which is a favourable characteristic and that sound blocks of a size consistent with Andra concept projects could exist in this layer. However, IRSN recommended caution when extrapolating data acquired in the laboratory to a wider scale, given the possible co-existence of faults of similar origin but with varying expression within the host formation.

On a methodological point of view, IRSN concluded that using the 3-D seismic survey technique, combined with a survey of the clay formation itself via oblique boreholes upward from the most pronounced seismic indices in the underlying formations, should provide sufficient data to assess the structural characteristics of the sites that would be selected in a next stage of a repository project.

**Role of these structures on underground water flows and radionuclide transport**

In order to assess potential radionuclide transfers from the COX to the surface outlets, a groundwater flow model was built by IRSN in collaboration with the *Centre de Géosciences* of the *École des Mines de Paris*, using the computer code NEWSAM. Both the model and the code have evolved so as to incorporate new knowledge acquired through site characterisation and to deal with questions raised by the long term safety assessment, as illustrated below.

***Main characteristics of the hydrogeological model***

The hydrogeological model, intending to simulate the underground water flows and the salinity distribution throughout the Paris sedimentary basin, was produced using a multi-layer 3-D geological model representing the basin's various sedimentary layers. Since 1998, IRSN has gathered, in a hydrodynamic database called BPDATA (Gros and Bodilis, v. 2.6), information on hydraulic properties of the Paris basin and on salinity data found in literature. This data, as well as that acquired by Andra in the MHM boreholes, was introduced in the model. The model's calibration phase first consisted in matching the computed hydraulic heads as closely as possible with the measurements. Then, because of the presence of pure halite in high quantities in the eastern part of the Paris Basin within the Triassic, which can generate brines close to salt saturation and thus yield fluid density variations up to 25%, the density effects, coupled with the temperature effects on density variation, were taken into account, so as to also calibrate the hydrogeological model in terms of salinity (see de Hoyos *et al.*, 2008).

An important task was to deal with the influence of tectonic structures, which is a key question of the safety evaluation as they may have potential for locally leading to a channelling of flows through the different sedimentary beds and thus govern dilution factors, outlet positions and transfer times. The tectonic structures taken into account in the model came from a map of the main faults in the Paris basin (Guillocheau *et al.*, 2000) and from detailed mapping carried out by Andra at the MHM scale. In addition, IRSN carried out its own structural study at the MHM scale using another methodology than that applied by Andra, based on data obtained from DEM, 2-D seismic profiles, Andra boreholes and IRSN field tectonic analysis mentioned above, so as to further constrain the hydrological model. However, uncertainties remain concerning both the role of the regional faults at the MHM scale on hydrology, as well as concerning the presence and hydraulic role of smaller tectonic structures in the vicinity of a repository, which would be located, according to Andra (2005), at least a few kilometres away from regional faults.

***Hydrogeological model calibration accounting for a possible role of regional and secondary faults***

IRSN calibrated hydrogeological model yielded a correct representation of the various hydraulic heads and water salinities collected at a regional scale, i.e. throughout the Paris basin (IRSN, 2005). However, few hydraulic head measurements were available at the time of the study for calibrating the model in the MHM area. Hence, several flow schemes were able to correctly reproduce the measured heads. Among these various flow schemes, one did not give the tectonic structures a hydraulic role while the others did.

When no structure played a hydraulic role, calibrating the heads in the Oxfordian and Dogger formations required a limitation of flow exchanges between these two aquifers through the COX. This in turn required to consider significantly increased hydraulic conductivity values for the Dogger formation in the vicinity of the MHM area. While this hypothesis allowed for calculating piezometric levels that were consistent with the measured values, the hydrodynamic parameters used were not plausible. Indeed, the low hydraulic conductivity values measured by Andra were not consistent with the high values introduced into the model for the Dogger formation (IRSN, 2005).

A different approach was thus adopted, which aimed at assigning a hydraulic role to the tectonic structures that were mapped or suspected within the MHM investigated area. This approach led to different possible schemes consistent with the geological knowledge of the area. Two schemes in particular are discussed below. The fault transmissivities applied within the Oxfordian and the COX were identical in both schemes. The difference lied in the underlying Dogger aquifer. In Case No. 1, a very low matrix hydraulic conductivity was imposed within the Dogger formation combined with a network of secondary faults of high fracture transmissivity (in particular a potential fault oriented NW along the Saulx River; Figures 1, 9). Case No. 2 assumed a different distribution of transmissivity values for the secondary faults, in particular a lower transmissivity of the Saulx River fault in the Dogger formation (low matrix hydraulic conductivity kept unchanged). This calibration No. 2 then required an extent of the transmissive zone in the Bajocian outcrops (consistent with field observation of numerous karstic phenomena) and the definition, in that layer, of an area of low hydraulic conductivity within the eastern part of the MHM area.

Figure 9 shows the computed and measured hydraulic heads for the Oxfordian and upper Dogger (Bathonian) aquifers, for cases no. 1 and 2. The average fitting accuracy in the MHM area is less than 2 m in the Oxfordian and less than 3 m in the Bathonian, for both schemes. In order to discriminate between the possible schemes, additional field data should be collected. It is worth mentioning that for the “Dossier 2005” review (IRSN, 2005), Case No. 1, which in theory was more pessimistic (more transmissive faults), was chosen by IRSN to simulate radionuclide transport from the top of the COX to the biosphere outlets.

Figure 9. **Simulated hydraulic head values (colours) and measured head values (dots) for the Oxfordian and Bathonian aquifers, in Case No. 1 and Case No. 2**

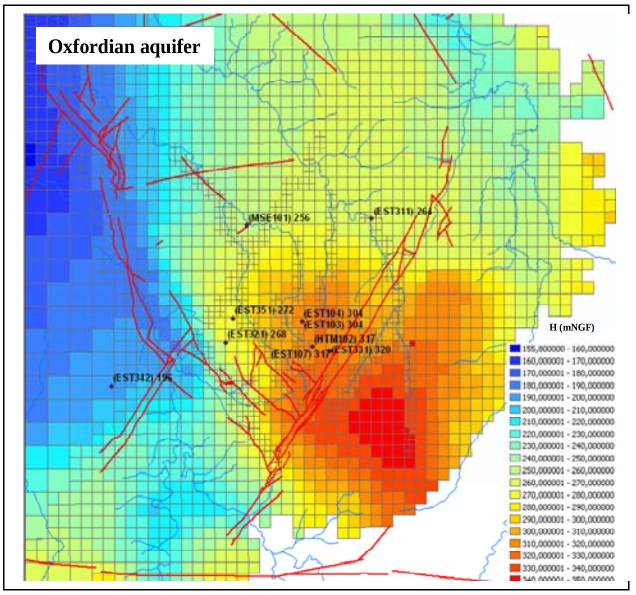
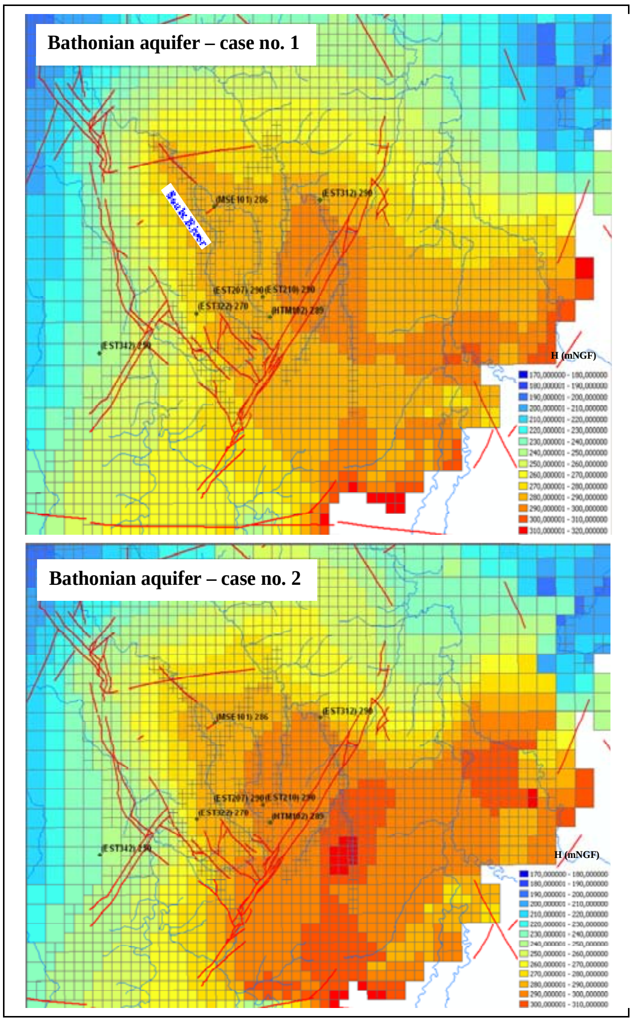


Figure 9. **Simulated hydraulic head values (colours) and measured head values (dots) for the Oxfordian and Bathonian aquifers, in Case No. 1 and Case No. 2** (Cont')

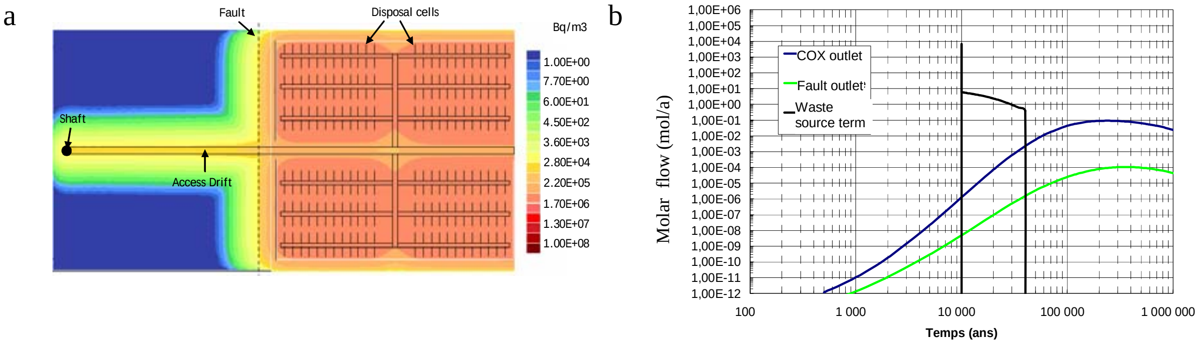



***Influence of a hypothetic secondary fault close to disposal cells on radionuclide transport***

Due to the present remaining uncertainty on the existence of hydraulically active secondary faults impacting the COX near the repository area, IRSN developed a so-called "what if" scenario using the MELODIE software, which aimed at assessing the influence of a hypothetic secondary fault close to disposal cells on radionuclide migration. IRSN considered a fault intercepting one of the shaft's access drifts in a computer model representing a spent fuel repository zone (cf. Figure 10a). This fault was assumed to be discovered during drift excavation. A clearance distance of 60 m was applied between the fault and the first repository cells, corresponding to half of the COX thickness. As a first approach, the adopted value for the fault permeability is low ($10^{-10}$ $m.s^{-1}$) with respect to possible transmissivities of equivalent structures observed in Tournemire (Savoye *et al.*, 2003). The kinematic porosity (9%) and transport parameters adopted for the fault (effective diffusion coefficient of $5\times10^{-12}$ $m^2.s^{-1}$; porosity accessible to diffusion of 5%) are similar to those of the non-fractured host rock as defined by Andra (2005) for anions. The fault was not sealed at its intersection with the drift in order to create a theoretically pessimistic situation, while the other linking drifts were sealed. A 0.2 m/m upward hydraulic gradient was applied to the whole model. Calculations were performed considering $^{129}I$ only, with a spent fuel release model provided by Andra (see IRSN, 2005).

The results of molar flow rates calculated at the top and bottom of the COX are summarised in Figure 10. The molar flow leaving via the fault ($10^{-4}$ mol/a) is lower by three orders of magnitude than the flux leaving via the rest of the COX sound rock ($9.10^{-2}$ mol/a). The maximum molar flow is achieved later for transfer to the fault outlet (350 ka) than for transfer through the sound rock (240 ka). 0.1 % of the activity stored initially (source term) leaves the COX via the fault compared to 77.6 % via the sound rock at the calculation time of $10^6$ a.

Figure 10. **a- Map of $^{129}$I concentrations (Bq/m$^3$) at 500 ka**
**b- $^{129}$I molar flow rate upward from a secondary fault and from the sound COX**




The results also showed (not illustrated herein) that the presence of the fault changes the molar flow rate around the disposal cells closest to the fault, but its influence on radionuclide migration is negligible at the disposal system scale. Nevertheless, uncertainties still remain on the hydrological properties of such a fault and on possible changes due to e.g. tectonics in the long term. Furthermore, the distance between a fault and the disposal cells remains an open issue. Improvements in detection techniques would thus be valuable with regard to the types of situations (i.e. fault location and properties) to be considered in long term evolution scenarios. More generally, such issues should be addressed with regards to safety strategy and design adaptation that would be preferred by the implementer.

**IRSN conclusions and perspectives**

Regarding structural discontinuities in the MHM area, the analysis of available field data collected by both Andra and IRSN and the analogy with IRSN observations at the Tournemire experimental station led IRSN to conclude that the COX might be locally impacted by tectonics in between the already mapped faults. Actually, as fracturing is observed in the outcrops of the clays' surrounding limestones, it cannot be excluded to take place in clays as well, even though a difference in fracture density is to be expected between both formation types. IRSN also noted that some structures with similar origin might have propagated across the COX while others have not. The propagation of fractures from limestones to clays is related to the so-called "differential fracturing phenomenon", implying that clay and limestone layers do not break the same way. This poorly understood phenomenon is being addressed by IRSN on the basis of field observations in analog sites (mainly in Malta Island and in Tournemire) at various scales (thin section up to formation scale), so as to elaborate a model of differential fracturing in clay/limestone alternations.

Regarding the survey methods to detect secondary structures in clay formations, a locally transmissive fault with a minor vertical offset in the clay formation may remain unidentified using the 2-D and 3-D seismic survey techniques. However, IRSN considered that using a 3-D seismic survey technique combined with a survey of the clay formation via oblique boreholes, notably right above the most pronounced seismic indices in the underlying formation, should provide sufficient data to assess the structural characteristics of a selected disposal site. Other methods presently under development may add valuable information. IRSN is currently testing various methods to detect secondary strike-slip faults that have already been identified in the Tournemire station. In particular, an electric tomography survey test was conducted (detailed in Cushing *et al.,* 2008), which turns out to be promising for locating hydrologically conductive zones.

In addition, the possible role of tectonic structures in MHM on underground water flows was addressed by IRSN. The simulations showed that the hydrogeological model was best calibrated, in terms of hydraulic heads as well as hydrodynamic parameters, when assigning a hydraulic role to tectonic structures within the MHM area. Several plausible hydraulic schemes came out of this calibration process. In order to discriminate between these different schemes, additional data should be collected from the field. In this objective, IRSN is currently carrying out structural mapping in the Dogger and Oxfordian aquifer formations in their recharge areas (east of MHM area).

Finally, IRSN radionuclide transport modelling has shown that the potential presence of a secondary fault close to disposal cells might have negligible influence on radionuclide migration at the disposal system scale. However, this simulation doesn't account for uncertainties remaining on both fault properties and fault evolution at short and long terms. More generally, IRSN estimates that improvements in detection techniques would be valuable with regard to the definition of the types of situations to be considered in long term evolution scenarios.

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